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STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA



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Final Report

CLOUD RESEARCH DATA

Prepared for:

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ABSTRACT

This report presents a summary and analysis of research on cloud cover conducted over a three-year period. During this time various sources of cloud data such as WBAN-10 reports, whole-sky photographs, vertically pointing radar records, and high-altitude photographs from U-2 aircraft and TIROS satellites were subjected to detailed analyses.

From these analyses we were able to obtain knowledge of: (1) the occurrence of multiple layers of clouds, (2) the frequency with which upper layers above an overcast may not be detected by a surface observer, (3) the length, width, and height of cumuliform clouds, and (4) the size distributions of cloud elements composing a given number of tenths of cumulus cloud cover.

Examples of our methods of treating these data, including pertinent illustrations and tables, are presented to indicate the detail with which the contract objectives were achieved.

ACKNOWLEDGMENT

The authors are indebted to Dr. M. G. H. Ligda for his invaluable advice during many phases of this work.

They also wish to thank Mr. H. Klieforth, AFCRL Field Project, Edwards AFB, California, for his help in obtaining the U-2 film without which detailed cloud measurements would not have been possible.

Thanks are also due to Miss Joyce H. S. Kealoha, Mrs. Arlyne Burris, and Messrs. A. Smith, M. Smith, P. Lester, and J. Harllee who assisted in the many details of data handling and illustrations required in the research.

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I INTRODUCTION

This contract, which started in April 1960, has explored the use of various types of cloud data to determine methods of more accurately specifying the nature and extent of cloud cover. The types of data subjected to detailed analyses include visual observations recorded on USWB form WBAN-10, records from vertically pointing radars, photographs from whole-sky cameras, U-2 photographs from high altitudes, and TIROS photographs of cloud cover as seen from space.

Our treatment of these data has yielded measurements of a number of cloud parameters essential to the quantitative description of cloud cover. Methods of data analysis and procedures for summarizing these measurements in a meaningful manner have been presented, during the course of the contract, in a series of five technical reports.

This Final Report summarizes and analyzes the research performed under the contract in the light of the specific research tasks. References are made to the previous Scientific Reports wherever necessary as a source of additional detail not repeated in this summary.

II RESEARCH TASKS

The initial contract had three research tasks listed in the statement of work. This statement was as follows:

"The contractor shall supply the necessary personnel, facilities, services, and materials to conduct studies and investigations relating detailed cloud data available to the scientific community from various cloud research programs and appropriate series of special radar cloud observations to standard visual airways and synoptic cloud observations made by several weather services. The desired goal of these studies is as follows:

- "(a) The determination of relationships and techniques by means of which the true or actual frequency of clouds at all altitudes can be computed from climatic cloud summaries which have been or can be prepared from standard visual surface observations.
- "(b) The development of analytical techniques (such as graphs, tables, or nomograms) which will provide a clear air-to-cloud relationship in significant detail from typical airways and synoptic weather reports of cloud type, altitude, and percentage sky cover.
- "(c) On the basis of results of (b) above, the determination of frequency distributions of the percentage of time that the sky and the ground are visible for angular increments of not more than 5 degrees and up to 30 degrees (depending upon the change of frequency with angle) from zero degrees to 90 degrees above and below the horizontal, from a vehicle moving horizontally at various altitudes."

The statement of work in the first one-year extension of the contract extended the work to include the newly available U-2 aircraft and TIROS I satellite data. Thus the initial work statement was modified by adding the following:

- "(d) Extend the determination of relationships and techniques by means of which the true frequency of clouds at all altitudes can be computed through the analyses of TIROS, U-2 and other specialized types of cloud data.
- "(e) Extend and expand the development of analytical techniques to provide the clear air-to-cloud relationships through additional analyses of TIROS, U-2 and other specialized types of cloud data."

The statement of work in the second one-year extension to the contract extended the analysis of U-2 and TIROS data and included a new area of approach by adding the following:

- "(f) Further expand the determination of the true frequency of clouds at all levels and the clear air-to-cloud relationships through greater emphasis and use of photographs from U-2 aircraft and TIROS satellites.
- "(g) Determination of altitude and thickness of cloud layers detected by vertically pointing (TPQ-11) radar, and analysis of optimum angle of view for evaluation of cloud structure."

III METHOD OF APPROACH

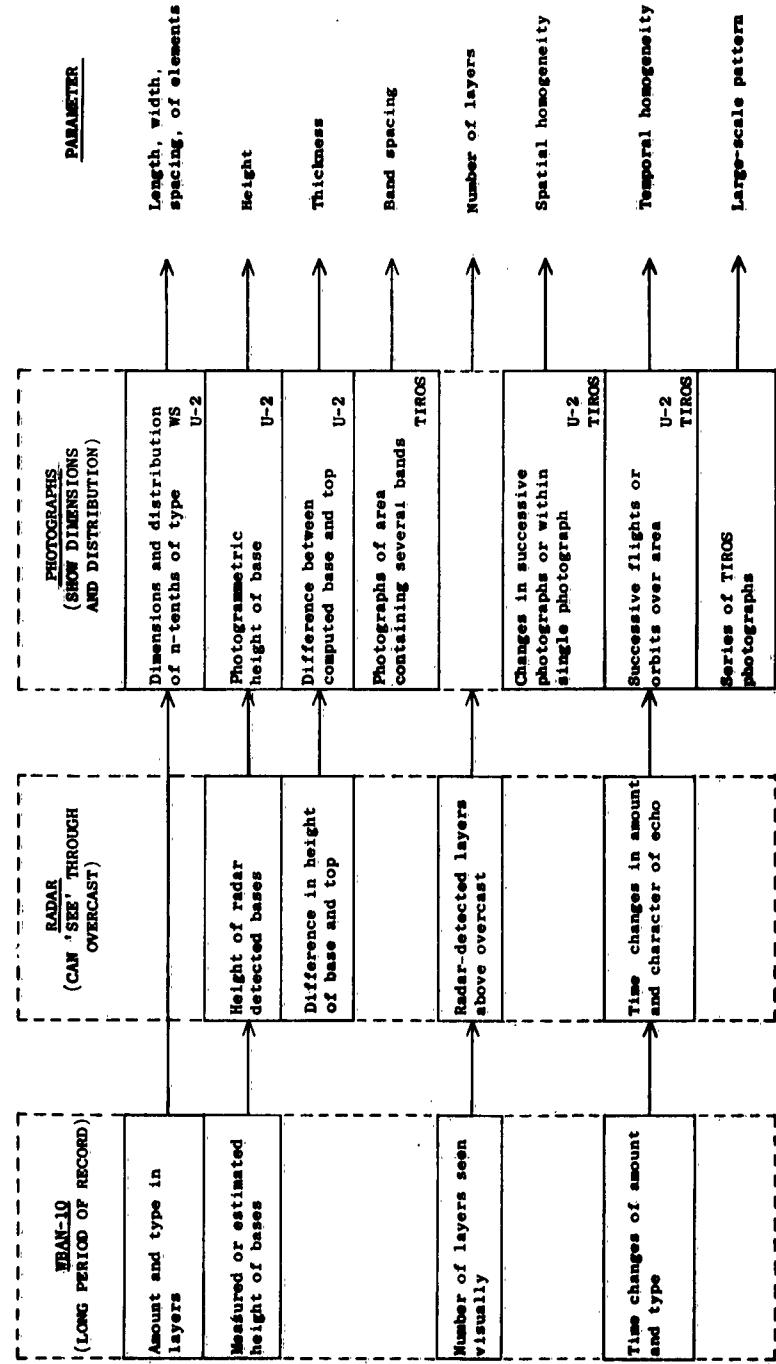
The various types of cloud data available to the scientific community were carefully scrutinized to determine the contribution each type of data could yield to the determination of a number of parameters we felt were essential to specifying true cloud cover. The parameters needed to specify true cloud cover are listed in Table I, together with the types of cloud data that are sources of information on one or several of the parameters. The table qualifies the extent to which the data sources provide satisfactory information on the various parameters. The table shows that each source of information provides knowledge on some of the parameters and each has limitations that restrict its use in determining other parameters.

Table II shows how the sources of information are integrated by utilizing as much information as possible from each data source to arrive at quantitative estimates of the required cloud parameters. This table clearly illustrates the necessity for photographs of cloud cover since only the photographs are capable of supplying much of the required information.

TABLE I
PARAMETERS NEEDED TO SPECIFY TRUE CLOUD COVER

PARAMETERS	VISUAL OBSERVATIONS ON WBAN-10	SOURCES OF INFORMATION			TIROS
		VERTICALLY- POINTING RADAR	WHOLE SKY	U-2	
Length and width of cloud elements	Length, width, and spacing vaguely implied by cloud type and amount	None	Only for small clouds (distorted)	Excellent	Mesoscale elements such as squall lines
Height of base and thickness	Only height of base recorded (to 9751 ft. during long period)	Complicated by rain	None	Can be computed	None
Spacing: Elements	Implied by amount and type	None	Only when spacing is small	Excellent	Poor
Bands	Implied by time changes in amount	None	Excellent	Excellent	Spacing of large- scale bands
Number of layers	Good when sky cover is less than 10/10	Good unless rain	Same as observer	Same as observer	None
Homogeneity: Spatial	Severely restricted	None	None	Good if planned	Very good if planned
Temporal	Changes in amount but not distribution	Only at Zenith	Good	Fair	Very good
Large-scale Pattern indications	Very poor	Very poor	Very poor	Fair	Very good

TABLE II
INTERACTION OF DATA TO OBTAIN DESIRED PARAMETERS



IV SUMMARY AND ANALYSIS OF RESEARCH

A. The True Frequency of Clouds at All Altitudes

The requirement concerning the true frequency of clouds at all altitudes is contained explicitly or implicitly in Tasks (a), (d), (f), and (g) as listed in Sec. II. Task (a) deals with techniques of computing the true or actual frequency of clouds at all altitudes from current cloud summaries. Toward this end, we evaluated cloud data summaries described in NAVAER-50-1C-534, "Guide to Standard Weather Summaries." Our evaluation showed that this guide provides very little pertinent information with respect to the true or actual frequency of clouds at all altitudes. Nor is it likely that one can obtain any but the grossest idea of the clear-air-to-cloud relationships.

The first paragraph of the introduction to NAVAER 50-1C-534 states in part: "... The basic precept of its preparation was that it would be an index of 'standardized' summaries available at the National Weather Records Center. An arbitrary definition of standardized was adopted which ignored...a large number of summaries prepared in accordance with very detailed and unique specification of limited interest to field activities and..."

There are a variety of "standardized" summaries in NAVAER 50-1C-534, some of which contain data on cloud cover. Titles of these cloud summaries are as follows:

- (1) "A Summary Only," p. 10, Format 22
- (2) "D Summary Ceiling vs. Visibility," p. 15, Format 25
- (3) "N Type Surface Summary," p. 29
 - (a) "Form 17. Total and Low Cloud Amounts and Percentage Frequency of Observations with Low Clouds."
 - (b) "Form 18. Percentage Frequency of Observations with Low Clouds and Visibility Reported."
- (4) "U.S. Navy Summary of Monthly Aerological Records; (SOMAR)," p. 35
 - (a) "Table 2 - Frequency of Low Cloud Amounts"
 - (b) "Table 3 - Frequency of Specified Ceiling Heights"

These "standardized" summaries serve aviation purposes primarily, because they describe conditions of ceiling and visibility.

For example, the table on page 10 titled "Sky Cover" fails to indicate:

- (1) Whether the clouds are low clouds, middle clouds, or high clouds
- (2) How often the sky cover between four-tenths and eight-tenths is composed of one layer, two layers, or three layers
- (3) When the sky cover is composed of cloud elements with spaces between the cloud elements as large as or larger than the clouds themselves.

Furthermore, consider Summary 17 on Page 29 of NAVAER 50-1C-534. It is possible to delineate only the frequency of low clouds compared to the total amount of clouds. A careful study of the table reveals that in this case low clouds are usually accompanied by middle and high clouds.

In Summary 18 on Page 29, the emphasis on low clouds is again fairly evident, but now in concert with specified visibilities. The summation of the data is primarily in terms of percentage frequency of closed, instrument, or contact flight conditions. Information as to how many times instrument or contact flight conditions were accompanied by middle or high clouds could generally only be inferred from a combination of the data in Summaries 17 and 18.

In the SOMAR Summaries, Table 2 on Page 35 is obviously of use only for low-cloud distribution.

The data in Table 3 on Page 35 show that better than 60 percent of the time the ceiling at Annapolis is above 9750 feet. This percentage includes those times during which there were no clouds in the sky as well as those times during which there were any number of clouds but the height of the bases was above 9750 feet. Thus, no information is available about middle or high clouds and it is impossible to ascertain the true frequency of clouds or clear-air-to-cloud relationship.

To obtain significant cloud climatologies organized so as not to exclude any knowledge about the true nature of cloud cover--e.g., the number and extent of multiple layers in those areas in which the sky cover is frequently reported as 10/10--existing WBAN-10 records must be updated. The updating should be accomplished to supply information about the occurrence of multiple layers under these conditions by programs such as we have outlined (in our Scientific Report 2), utilizing vertically pointing, specially designed radar, cloud photography programs from aircraft, and through the medium of satellites.

Methods of reanalyzing WBAN-10 records to extend their usefulness from a climatological point of view as well as methods of utilizing radar, cloud photographs, and TIROS photographs were considered under Tasks (d), (f), and (g) of the statement of work.

In our opinion, the parameters that are essential to adequately describe the true frequency of clouds at all altitudes are the number, height, and thickness of cloud layers. Reference to Table 2 shows that these parameters are contained in WBAN-10 forms, radar records, and U-2 photographs. Our treatment of these data was described in detail in Scientific Report 2 (and radar data was further discussed in Scientific Report 5). Summaries of the type shown in Fig. 1 were devised to best portray the following information from WBAN-10 reports:

- (1) The number of hours each number of tenths occurred (total height of bar)
- (2) The number of times one layer (narrow bar), two layers (bar of double width) and three layers (bar of triple width) occurred in each tenth interval (indicated at the tops of the bars)
- (3) The type of clouds making up the single or multiple layers. (The abbreviation of the cloud type is entered in the bar with the number of occurrences of the cloud type or combination of types.)

Summaries of the type illustrated in Fig. 1 may be analyzed further to yield comparative frequencies of single or multiple layers as was done in Scientific Report 2.

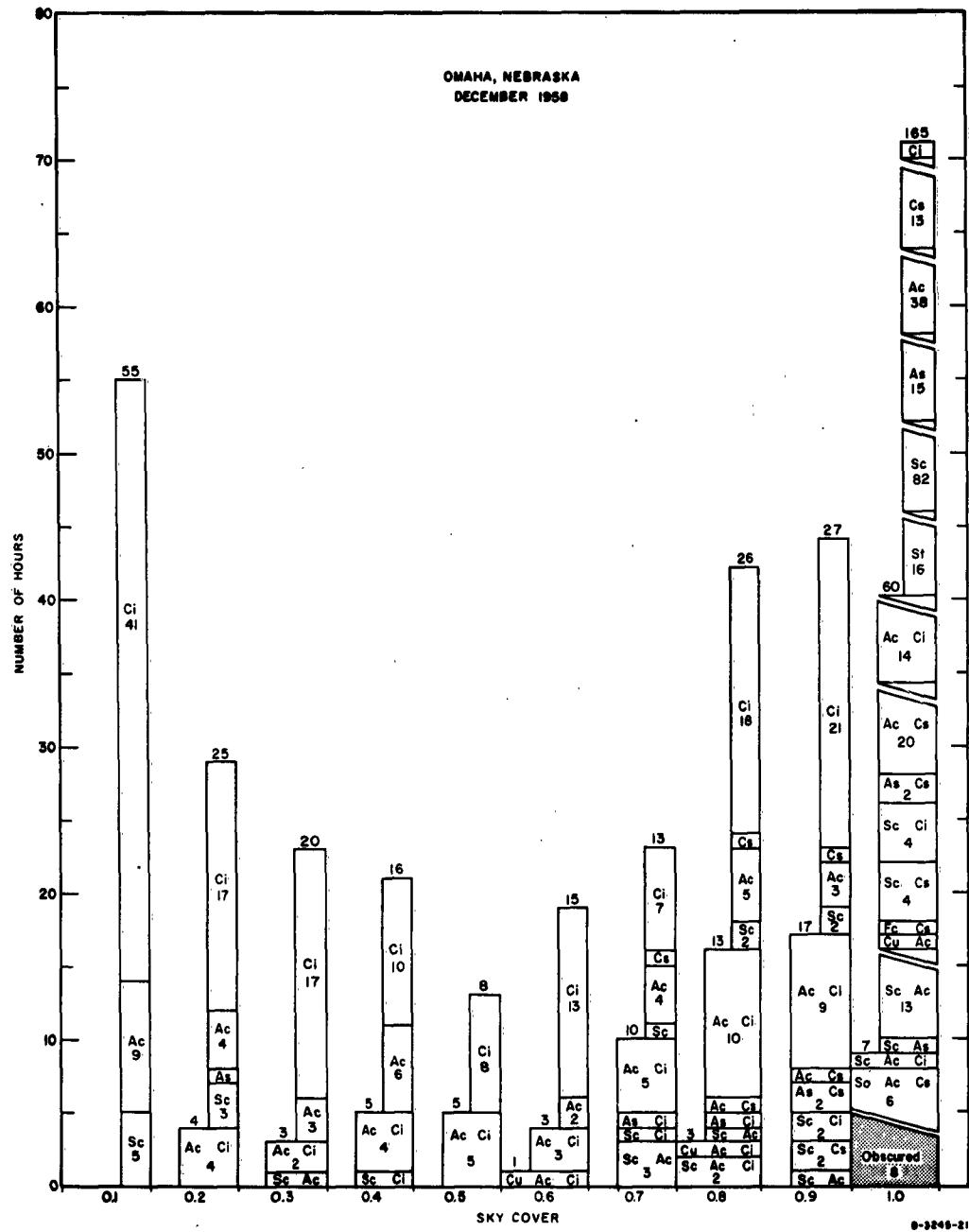


FIG. 1 DISTRIBUTION OF CLOUD TYPES AND LAYERS BY CLASS

From these and other studies we concluded that the information on the true nature of cloud cover which must be contained in a comprehensive cloud climatology is:

- (1) Percent of time the sky is clear
- (2) Percent of time the sky is overcast
- (3) Percent of cloud observations reporting each tenth interval
- (4) Distribution of layers in each tenth interval
- (5) Cumulative frequencies of Items 3 and 4
- (6) Most frequent cloud types at each level.

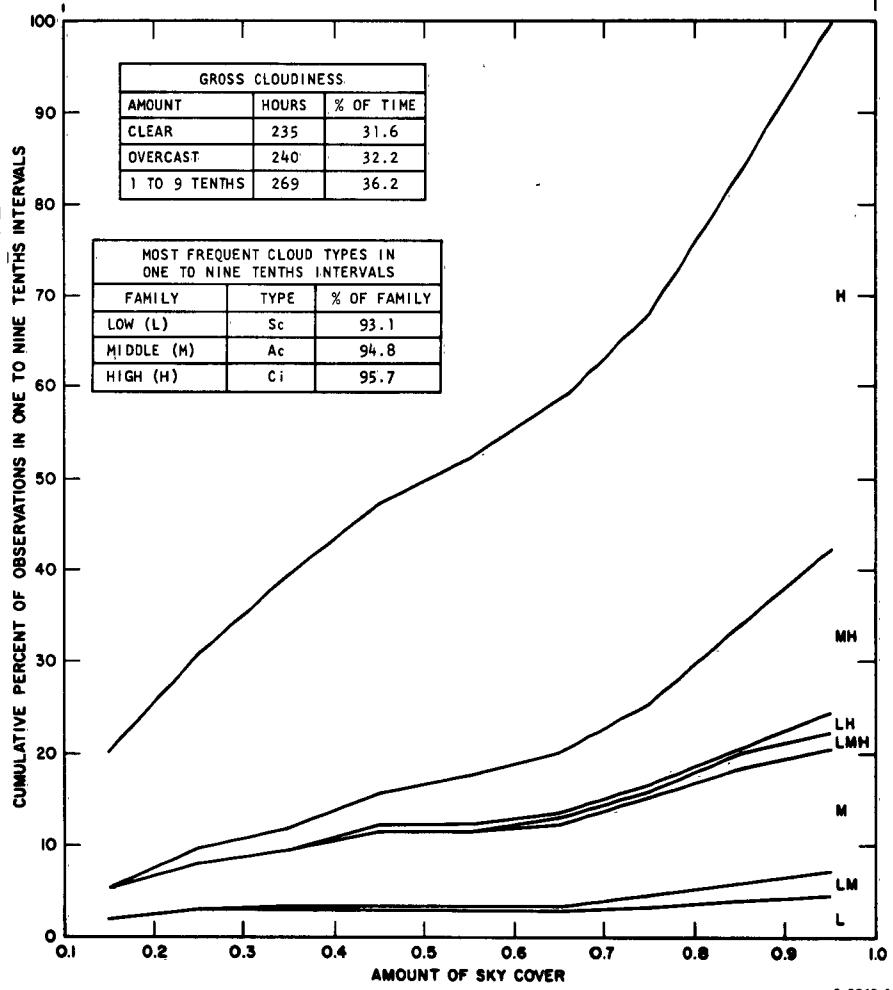
Much of this information as given by WBAN-10 reports was organized for presentation in a special type of diagram which contains three tables and a series of cumulative frequency curves (see Fig. 2). One table on the diagram gives the percent of cloudy hours composed of various layers or combination of layers in each tenth interval. A second table gives the percent of time that the sky was clear, overcast, or one-tenth to nine-tenths covered. A third table gives the most frequent cloud type (or types if one type is not observed a substantial majority of the time) at the low, middle, and high levels.

The cumulative-frequency curves on the diagram give information on the cumulative frequencies of the individual layers or combinations of layers and on the cumulative frequencies of the tenths intervals.

The problem of determining whether or not upper clouds may exist above a low overcast was investigated with the use of data from a vertically pointing radar. These investigations (described in detail in Scientific Reports 2 and 5) led to a method of statistically correcting the surface reports. Table III illustrates the manner in which such a correction might be made. The use of this technique would require that long periods of WBAN-10 records be separated into climatic zones and synoptic situation. Then, based on the radar records from similar synoptic situations in a given climatic zone, the visual observations in the various categories could be amended or upgraded to include one or more cloud layer(s) above the low overcast. The frequency of clouds .

FREQUENCY IN CLASS AND CUMULATIVE FREQUENCY (IN PARENTHESIS) OF CATEGORIES

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
H	15.2 (15.2)	6.3 (21.5)	6.3 (27.8)	3.7 (31.5)	3.0 (34.5)	4.8 (39.3)	3.0 (42.3)	7.1 (49.4)	8.2 (57.6)
MH		1.5 (1.5)	0.7 (2.2)	1.5 (3.7)	1.9 (5.6)	1.1 (6.7)	2.2 (8.9)	4.5 (13.4)	4.5 (17.9)
LH				0.4 (0.4)	0 (0.4)	0 (0.4)	0.4 (0.8)	0 (0.8)	1.5 (2.3)
LMH						0.4 (0.4)	0 (0.4)	1.1 (1.5)	0 (1.5)
M	3.3 (3.3)	1.9 (5.2)	1.1 (6.3)	2.2 (8.5)	0 (8.5)	0.7 (9.2)	1.5 (10.7)	1.9 (12.4)	1.1 (13.7)
LM			0.4 (0.4)	0 (0.4)	0 (0.4)	0 (0.4)	1.1 (1.5)	0.4 (1.9)	0.4 (2.3)
L	1.9 (1.9)	1.1 (3.0)	0 (3.0)	0 (3.0)	0 (3.0)	0 (3.0)	0.4 (3.4)	0.7 (4.1)	0.7 (4.8)



C-3245-2

FIG. 2 PRESENTATION OF CLIMATOLOGICALLY SIGNIFICANT DETAILS OF CLOUD COVER
(Based on data from Omaha, Nebraska, December 1958)

at various altitudes would be much more nearly correct if, for example, the radar showed that for one-third of the time during which the observer could see only a single lower layer there was also a middle layer present.

Table III
OBSERVED VS. RADAR-CORRECTED CLOUD COVER

No. of visual Observations in various categories	Number of observations in various categories when radar-detected layers are added to visual observations						
	L	LM	LH	LMH	M	MH	H
L 3	1		1	1			
LM 3		1		2			
LH 2			2				
LMH 0							
M 3						3	
MH 0							
H 0							

B. Clear-Air-to-Cloud Relationships

Tasks (b), (e), and (f) are concerned with clear-air-to-cloud relationships. The determination of such relationships requires knowledge of the length, width, thickness, and spacing of the cloud elements. The variability of the clear-air-to-cloud relationships requires knowledge of the spatial and temporal homogeneity of the cloud cover. Reference to Table II shows that the required cloud parameters may best be obtained from U-2 films. Our analyses of U-2 films were described in detail in Scientific Report 4. In these analyses we divided clouds into three classes: CL1, CL2, and CL3, as illustrated in Fig. 3. For each of these classes we were able to specify the number of clouds over a given area as a function of the total cloud cover within the area. Table IV shows the contribution of clouds of various sizes to the total cloud cover. To show the interrelation of such cloud distributions over a fairly broad area we prepared two large mosaics of cloud cover (distributed as Scientific Report 3) over an extended area during two U-2 flights on

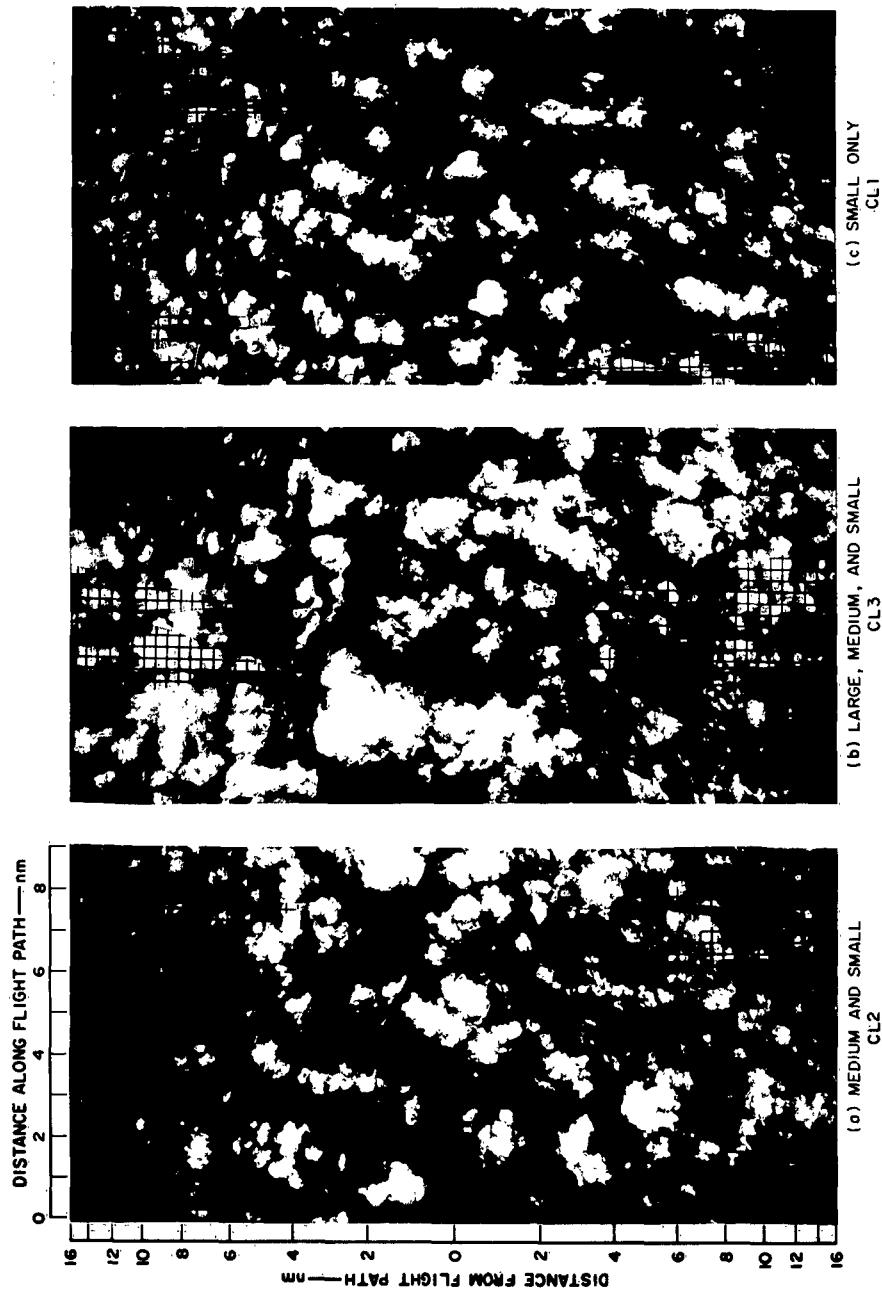


FIG. 3 TYPICAL DISTRIBUTION OF CUMULUS CLOUD TYPES AS SHOWN BY U-2 FILM

Table IV
PERCENTAGE OF TOTAL CLOUD COVER
CONTRIBUTED BY CLOUDS OF VARIOUS SIZES

Cloud Size (sq. nm)	Reported Clouds (Percent)		
	CL1	CL2	CL3
0.1	55.0	25.0	20.0
0.5	25.0	24.0	11.5
1.0	16.0	18.5	11.0
2	3.0	12.0	9.5
3	1.0	6.0	5.5
4		4.0	5.0
5	N	3.0	4.0
6	O	2.5	3.5
7	N	2.0	3.0
8	E	1.5	3.0
9		1.0	2.5
10	P	0.5	3.0
12	R		3.5
14	E		3.5
16	S		2.5
18	E	None	2.5
20	N	Present	3.0
25	T		3.0
30			0.5

25 April 1960 and 28 July 1960. These mosaics provide a great insight into the spatial homogeneity of the cloud cover--i.e., the extent to which there is or is not intermingling of clouds of all dimensions. A beginning was also made in showing the ability of the extensive TIROS data catalogue to provide examples of similar cloud cover in regions in other parts of the hemisphere. An examination of the synoptic data that can be correlated with such comparative catalogues will yield much important knowledge of other meteorological parameters of operational

importance. This will indirectly extend the network of information with regard to these parameters, since TIROS provides continuous coverage and we will be able to extract data at any number of point sources or regions in which there are no other observing facilities. Including such data in our future studies will lead to heightened and much more definitive climatological studies; especially in establishing rather clearly where one climatic region ends and another begins. Such boundaries are currently not clearly marked in areas of sparse data and over the vast oceanic regions.

C. Frequency Distribution of the Percent of Time the Sky and Ground Are Visible

All the parameters described previously are essential to the determination of the percent of time the ground is visible through cloud cover. An equation relating the cloud parameters and including several non-cloud parameters was derived to express this percentage. The basic equation is

$$P = 100 - 100 \left\{ \frac{(H - h) [\text{Cot}(\alpha + \beta) - \text{Cot}(\alpha - \beta)]}{S + W} + T \text{Cot}(\alpha - \beta) + W \right\}$$

where:

P = Percent of time the ground is visible

h = Height of cloud base (feet)

T = Vertical extent of clouds (feet)

S = Distance between clouds (nautical miles)

W = Width of clouds (nautical miles).

Non-cloud parameters necessary to the equation were:

H = Height of vehicle (feet)

α = Angle of view (degrees)

F = Field of view (degrees)

β = $1/2$ field of view $\left(\frac{F}{2}\right)$ (degrees).

To permit rapid solution of this and the other equations in Scientific Report 1 over a wide range of cloud parameters without resorting to expensive automatic computing devices, nomographic charts were constructed. One such chart is illustrated in Fig. 4.

The nomograms yield the percent of time the ground or sky is visible with any given set of cloud parameters. Additional studies of the type described in Sec. IV-B will provide characteristic frequency distributions of the parameters so that one may specify the necessary visibility parameter in any of a number of statistically meaningful categories.

INSTRUCTIONS FOR USE OF FIG. 4

Note: It is helpful to follow through the instructions once or twice using a clear plastic straightedge on the small insert on the figure. It should be noted that there are two W scales and two α scales. This was necessary because these parameters both enter the equation twice. When solving the equation, the same value of W must be used on both W scales, and the same value of α must be used on both α scales.

- (a) Lay straightedge across given values of S and W_2 (see Note, and see Line labeled a on inset). Mark index Point 1, where straightedge intersects h, T scale, for future use.
- (b) Lay straightedge across given values of T and α_1 (see Note, and see Line b). Place pencil at Index Point 2, where straightedge intersects S scale.
- (c) Pivot straightedge on Point 2 to value of W_1 (see Line c) and mark Index Point 3, where straightedge intersects h, T scale.
- (d) Lay straightedge across given values of h and H (Line d).
- (e) Place pencil at Index Point 4, where straightedge intersects W_1 , W_2 scales, and pivot straightedge to value of α_2 (Line e).
- (f) Move pencil to Index Point 5 (H scale) and pivot to Index Point 3 marked in Step (b) (Line f) on H, T scale. Move pencil to Index Point 6 on S scale and pivot straightedge to Index Point 1 Marked in Step (a) on H, T scale. The answer is now at the point where the straightedge crosses the P scale.

EXAMPLE: When

$$\begin{aligned}S &= 5 \text{ nautical miles} \\W &= 5 \text{ nautical miles} \\T &= 20,000 \text{ feet}\end{aligned}$$
$$\begin{aligned}\alpha &= 40 \text{ degrees} \\h &= 5,000 \text{ feet} \\H &= 50,000 \text{ feet}\end{aligned}$$

then $P = 33$ percent.

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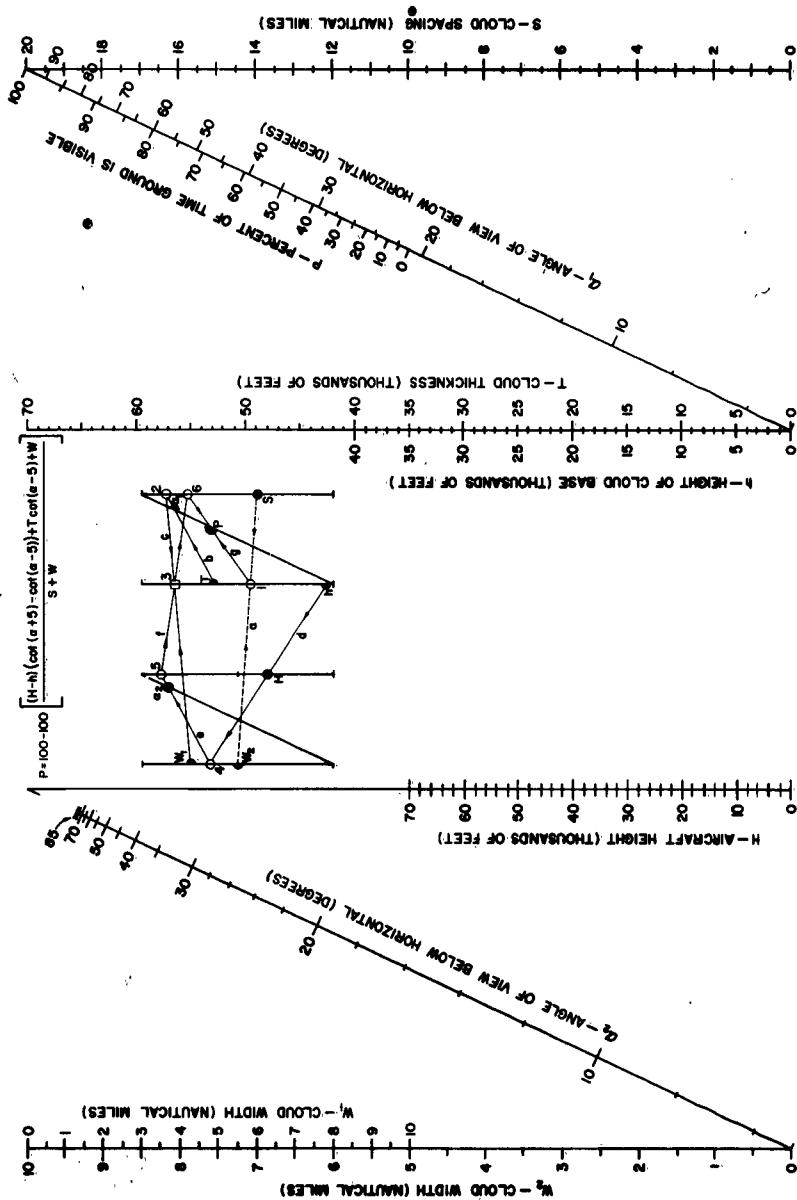


FIG. 4 NOMOGRAPHIC CHART FOR DETERMINATION OF THE PERCENT OF TIME
THE GROUND IS VISIBLE

V CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The research summarized in this report shows the ways in which it is possible to utilize newly available types of cloud data to supplement and interpret the long period of record of surface cloud observations. Through such supplementation and interpretation, cloud climatologies may be constructed that will be operationally significant for current and future aerospace requirements. Further investigation is essential on many fronts in order to ensure that such cloud climatologies provide a complete spectrum of information which will serve as important initial input into many problems that encompass large geographic areas up to hemispheric in size. Comprehensive cloud information is essential to

- (1) Infrared estimates of total radiation and heat budget studies
- (2) Photographic reconnaissance
- (3) Help reinforce similarities between climatic zones or point out climatic differences (from a cloud-cover point of view) in similar geographic areas
- (4) Operation of horizon sensors
- (5) Launching, re-entry, and recovery of aerospace vehicles
- (6) Help differentiate the nature of cloud cover in those areas where the cloud cover is primarily orographic, as compared with that cloud cover associated with large- and small-scale weather systems.

Studies that will yield knowledge pertinent to the above areas of interest are in part currently in progress at SRI under a new contract with the U.S. Air Force. The objectives of these continuing studies were formulated for the large part on the basis of results and conclusions of the project which is the subject of this final report. New tasks were defined as new directions were indicated and new needs discovered, in order to augment the available information about cloud cover so that it would yield significant climatological data. We feel certain that as a result of these and continuing studies much information of military and non-military significance will be generated for those stratagems in which the problem of cloud cover is of great concern.

SUMMARIES OF SCIENTIFIC REPORTS ISSUED UNDER THIS CONTRACT

Scientific Report 1 - AFCRL 266 - December 1960

**DETERMINATION OF THE PERCENT OF TIMES THE GROUND IS VISIBLE FROM
AN AIRCRAFT FLYING ABOVE CLOUDS**

By: Roy H. Blackmer, Jr., and John Harllee

The parameters required to express the percent of time the ground is visible from a vehicle moving horizontally at various altitudes were investigated. It was found that the simplest possible solution (only two dimensions) required knowledge of height of cloud base, thickness of clouds, spacing of clouds, width of clouds, height of vehicle, angle of view, and field of view.

Equations relating these parameters were derived and a series of nomographic charts were constructed for the solution of the equations over a wide range of values of the parameters.

Scientific Report 2 - AFCRL 698 - June 1961

AN INVESTIGATION TO ESTABLISH THE TRUE NATURE OF CLOUD COVER

By: Sidney M. Serebreny and Roy H. Blackmer, Jr.

This report discusses techniques by which visual observations recorded on WBAN-10 forms, records from vertically pointing radar, and whole-sky photographs can be used to establish the true nature of cloud cover.

Visual observations are discussed in two major classes: (1) sky cover from one-tenth to nine-tenths and (2) sky cover of ten-tenths. In the discussion of the first class, methods of summarizing these WBAN-10 observations to preserve information on simultaneous occurrence of two or more cloud layers in each reporting interval are described (and illustrated in Appendix A), as well as the composition of the layers. This information is presented in charts which relate the contributions of single and multiple layers to the cumulative frequency of cloud amount.

SUMMARIES OF SCIENTIFIC REPORTS ISSUED UNDER THIS CONTRACT

Scientific Report 1 - AFCRL 266 - December 1960

DETERMINATION OF THE PERCENT OF TIMES THE GROUND IS VISIBLE FROM
AN AIRCRAFT FLYING ABOVE CLOUDS

By: Roy H. Blackmer, Jr., and John Harllee

The parameters required to express the percent of time the ground is visible from a vehicle moving horizontally at various altitudes were investigated. It was found that the simplest possible solution (only two dimensions) required knowledge of height of cloud base, thickness of clouds, spacing of clouds, width of clouds, height of vehicle, angle of view, and field of view.

Equations relating these parameters were derived and a series of nomographic charts were constructed for the solution of the equations over a wide range of values of the parameters.

Scientific Report 2 - AFCRL 698 - June 1961

AN INVESTIGATION TO ESTABLISH THE TRUE NATURE OF CLOUD COVER

By: Sidney M. Serebreny and Roy H. Blackmer, Jr.

This report discusses techniques by which visual observations recorded on WBAN-10 forms, records from vertically pointing radar, and whole-sky photographs can be used to establish the true nature of cloud cover.

Visual observations are discussed in two major classes: (1) sky cover from one-tenth to nine-tenths and (2) sky cover of ten-tenths. In the discussion of the first class, methods of summarizing these WBAN-10 observations to preserve information on simultaneous occurrence of two or more cloud layers in each reporting interval are described (and illustrated in Appendix A), as well as the composition of the layers. This information is presented in charts which relate the contributions of single and multiple layers to the cumulative frequency of cloud amount.

In the analysis of observations of ten-tenths sky cover, particular attention is paid to the situations wherein an observer would miss one or more layers of clouds because of a lower overcast.

Examination of the rapidity of change in cloud cover with time shows that observations of either clear or overcast tend to be repeated for many consecutive hours, while observations of one to nine-tenths are seldom identically repeated for prolonged periods.

Studies of the contributions that vertically pointing radar can make to the determination of true cloud cover resulted in the formulation of a method of comparing visual and radar observations to determine the frequency with which the observer cannot see upper layers.

In addition initial results of measurements of cloud dimensions from whole-sky photographs are presented in a series of charts relating cloud dimensions to space between clouds and to the amount of sky covered by the clouds.

Photographs showing the differences in areal coverage by whole-sky cameras, U-2 cameras, and wide- and narrow-angle TIROS I cameras are included to illustrate the spectrum of dimensions of cloud cover which must be considered for a complete delineation of cloud cover.

Scientific Report 3 - AFCRL-62-269 - March 1962

PATTERNS OF CLOUD COVER SHOWN BY U-2 PHOTOGRAPHY

By: Sidney M. Serebreny, and Roy H. Blackmer, Jr.

Two series of panoramic cloud mosaics constructed from a number of photographs selected to illustrate the types of cloud cover with which our studies are concerned were presented in this report in a unique manner, such that each figure (2 feet by 5 feet) could serve as a wall display. For each of two mosaics (25 April 1960 and 28 July 1960) the following information was presented:

- (1) The broadscale cloud cover over a selected area
- (2) A schematic representation of the heights of the clouds within the central portion of the area photographed
- (3) The ratio of cloud area to ground area (tenths of cloud cover)

- (4) A cross section of the terrain and clouds along the flight path
- (5) A surface weather map for the time closest to flight time.

In addition, a TIROS I cloud photograph was included to show cumulus cloud bands strikingly similar to those photographed from the U-2 on the 28 July 1960 flight. This photograph was for 23 May 1960 from another area of the globe.

Scientific Report 4 - AFCRL-62-609 - July 1962

DIMENSIONS AND DISTRIBUTIONS OF CUMULUS CLOUDS
AS SHOWN BY U-2 PHOTOGRAPHS

By: R. H. Blackmer, Jr., and S. M. Serebreny

This report presents the results of analyses of cumulus cloud dimensions and distributions derived from high-altitude photographs of cloud cover taken by U-2 aircraft on flights from Cape Canaveral, Florida, to Edwards Air Force Base, California, on 28 July 1960 and 5 August 1960. Photogrammetric analyses of these films provided measurements of the thickness, length, width, and spacing of the clouds. Distributions of these parameters for all the cumulus clouds are presented.

Analyses were made of the relationships between length and width and between horizontal extent and vertical extent of the clouds. These analyses showed that only about one-third of the clouds were circular and some clouds had lengths more than three times as great as the widths. The comparison of horizontal and vertical extent showed that increases in thickness and length were nearly equal.

Cloud areas were divided into three classes on the basis of the presence of (1) only small clouds, (2) medium and small clouds, and (3) large, medium, and small clouds. These classes are felt to be equivalent to the internationally defined genera of cumulus CL1, CL2, and CL3. The distributions of dimensions of these classes are shown together with a discussion of surface observations of cloudiness made concurrently with the photographs. Finally, examples of cloud distributions as shown by rocket and satellite photographs are presented, and the role of these data sources in future cloud studies is mentioned briefly.

Appended to the report is a discussion of the techniques of photogrammetric analysis.

Scientific Report 5 - February 1962

CONSIDERATIONS OF CLIMATOLOGICAL APPLICATIONS OF
VERTICALLY POINTING WEATHER RADAR OBSERVATIONS

By: R. H. Blackmer, Jr., and Myron G. H. Ligda

This report presents a discussion of the potential climatological utilization of vertically pointing weather radar observations.

The discussion includes such factors as the optimum tilt angle and antenna rotation rate to detect scattered clouds often missed by a fixed vertical antenna. Examples of the probable appearance of several cloud distributions as shown by fixed and scanning antennas are presented.

A suggested method of summarizing the data for climatological purposes by the utilization of punched cards is presented in the final section of the report.

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PAPERS AND PUBLICATIONS BY PROJECT PERSONNEL

Serebreny, Sidney M., "Cloud Research at SRI," paper presented at Technical Conference on Cloud Observation, Description, Analysis and Prediction, at Hanscom Field, Bedford, Mass., October 1961.

Blackmer, Roy H., Jr., "Cloud Distributions Within Areas of Thunderstorms," paper presented at the Tenth Weather Radar Conference, Washington, D.C., April 1963.

Two papers that are being prepared for publication in Professional Journals will acknowledge sponsorship of the research under this contract.

LIST OF PROJECT SCIENTISTS

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	UNCLASSIFIED		
AF Cambridge Research Laboratories, Bedford, Massachusetts, Geophysics Research Directorate CLOUD RESEARCH DATA, by S. M. Serebreny and R. H. Blackmer, Jr., February 1963. 33 pp. Unclassified Report	1. Cloud Cover I. S. M. Serebreny II. R. H. Blackmer, Jr.	AF Cambridge Research Laboratories, Bedford, Massachusetts, Geophysics Research Directorate CLOUD RESEARCH DATA, by S. M. Serebreny and R. H. Blackmer, Jr., February 1963. 33 pp. Unclassified Report	This report presents a summary and analysis of research on cloud cover conducted over a three-year period. During this time, various sources of cloud data such as WBAN-10 reports, whole-sky photographs, vertically pointing radar records, and high-altitude photographs from U-2 aircraft and TIROS satellites were subjected to detailed analyses. From these analyses, we were able to obtain knowledge of: (1) the occurrence of multiple layers of clouds, (2) the frequency with which upper layers above an overcast may not be detected by a surface observer, (3) the length, width, and height of cumuliform clouds, and (4) the size distributions of cloud elements.
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